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Industry structure and compliance with environmental standards

Dale H. Chua
Université Laval, Quebec, Quebec, Canada

Peter W. Kennedy
University of Victoria, Victoria, British Columbia, Canada

Benoit Laplante
Université Laval, Quebec, Quebec, Canada

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This paper analyses the relationship that exists between the expected level of non-compliance with environmental regulations and the number of firms in the industry. It shows that the larger the number of firms, the higher the equilibrium expected probability of compliance.

1. Introduction

Though environmental regulations have now been in use for more than 20 years, it is increasingly recognized that their efficacy in controlling pollution emissions has been dampened by a lack of appropriate monitoring and enforcement. Indeed, resources devoted by various regulatory agencies to the monitoring and enforcement of pollution emissions standards have typically been characterized as being insufficient. Russell (1990) asserts that 'What is missing is a commitment of resources to checking up on whether those covered by the law and regulations are doing (or not doing) what is required of (or forbidden to) them' (p. 243).

Hence, the regulator finds itself in a position where it has to allocate scarce resources in order to perform a limited number of monitoring activities. If the regulator's objective is to monitor firms in industries where it is more likely to observe non-compliance, then, in order to make the most of its limited resources, it should be adept at using observable characteristics of industries that identify where the expected probability of non-compliance with the emissions standards is likely to be high. Silverman (1990) reports that each EPA program has developed monitoring strategies in such a way that 'the most intensive efforts are directed at those segments of the regulated community most likely to be in non-compliance' (p. 95). One such observable characteristic is the number of firms in

Correspondence to: B. Laplante, Groupe de Recherche en Économie de l'Énergie et des Ressources Naturelles, Département d'économique, Université Laval, Ste-Foy, Québec, Canada, G1K 7P4.

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the industry. Using a stylized model, this paper shows that the smaller the number of firms in an industry, the higher is the expected level of non-compliance with the emissions standard. [1] Section 2 develops the basic model and presents the main results. Section 3 discusses some policy implications.

2. The model and main results

Consider a n-firm industry producing a homogeneous good. The marginal cost of production for each firm is constant and equal to c_0. Pollution is a by-product of the production process. Though firms are subject to a binding emissions standard, they may or may not choose to comply with it. If compliance is the chosen strategy, the marginal cost of production increases from c_0 to c_1. [2] The market demand function for the good is $P = a - b\Sigma_{i=1}^{n} q_i$ where q_i is the output of firm i, with $b > 0$ and $a > c_1 > c_0$. For any given firm, the probability of being monitored is β. If a non-complying firm is monitored, it faces a penalty equal to F. [3] The question of compliance incentives is relevant only if F *cannot* be set arbitrarily high. An extensive literature exists on why penalties for law violation are limited. [4] We return to this issue in section 3. For the moment F is simply taken as given.

The problem is modelled as a two-stage game. In the first stage the firm chooses whether or not to comply with the emissions standard. Let α denote the probability of compliance (we allow for the possibility of mixed strategies). [5] In the second stage, the firm chooses its optimal level of output, given its decision to comply or not comply. In order to characterize the symmetric subgame perfect Nash equilibria, we begin by solving the second-stage problem.

Stage 2

Firm i chooses its optimal level of output to maximize its expected profits $\mathrm{E}\,\pi_k^i$ by solving

$$\max \mathrm{E}\,\pi_k^i = q_k^i\left[a - b\left(q_k^i + \mathrm{E}\,q^{-i}\right)\right] - c_k q_k^i, \tag{1}$$

where k equals 0 if firm i has chosen not to comply with the emissions standard and equals 1 otherwise. Firm i's expectation of the other firms' level of output is denoted by $\mathrm{E}\,q^{-i}$. The solution to this maximization problem yields firm i's reaction function:

$$q_k^i = \left(a - c_k - b\,\mathrm{E}\,q^{-i}\right)/2b. \tag{2}$$

[1] Though the paper is developed using environmental regulations, it could equally be applied to other types of regulation with similar compliance consequences.

[2] Fixed costs of compliance are assumed to be zero. Positive fixed costs will have no impact on our results as long as individual profits are positive for any given number of firms. It is noteworthy that when the Clean Air Act was introduced, US coalburning power plants found it optimal to shift from high-sulfur content coal to higher cost low-sulfur content coal rather than install scrubbers.

[3] This penalty comprises the fines imposed by tribunals and may include legal costs as well as the loss of reputation if the prosecution is publicized.

[4] See Becker (1968), Malik (1990), Polinsky and Shavell (1979, 1984, 1991), and Stigler (1970).

[5] We have modelled the firm's problem as a one-shot game. In a repeated game, α can be interpreted as the frequency of compliance. Our results extend to a repeated setting as long as the probability of being monitored is serially independent.

Let $\hat{q}_k^i$ denote firm i's equilibrium level of output. In a symmetric Nash equilibrium, $\hat{q}_k^i = \hat{q}_k$, $\forall\ i$. Denote by $\hat{\alpha}$ the equilibrium probability of compliance. Hence, in (2)

$$\mathrm{E}\, q^{-i} = \hat{\alpha}(n-1)\hat{q}_1 + (1-\hat{\alpha})(n-1)\hat{q}_0. \tag{3}$$

Using (2) and (3), we can solve simultaneously for $\hat{q}_0$ and $\hat{q}_1$:

$$\hat{q}_0 = [2(a-c_0) + \hat{\alpha}(n-1)(c_1-c_0)]/2b(n+1) \tag{4a}$$

and

$$\hat{q}_1 = [2(a-c_1) - (1-\hat{\alpha})(n-1)(c_1-c_0)]/2b(n+1). \tag{4b}$$

These equilibrium levels of output give rise to the following expected equilibrium profits:

$$\mathrm{E}\,\hat{\pi}_0 = [2(a-c_0) + \hat{\alpha}(n-1)(c_1-c_0)]^2/4b(n+1)^2 \tag{5a}$$

and

$$\mathrm{E}\,\hat{\pi}_1 = [2(a-c_1) - (1-\hat{\alpha})(n-1)(c_1-c_0)]^2/4b(n+1)^2. \tag{5b}$$

Stage 1

Firm i chooses the strategy that yields the highest level of profits. This implies the following decision rule:

$$\alpha = \begin{cases} 0 & \text{if} \quad \mathrm{E}\,\hat{\pi}_0 - \beta F > \mathrm{E}\,\hat{\pi}_1, \\ \in (0,1) & \text{if} \quad \mathrm{E}\,\hat{\pi}_0 - \beta F = \mathrm{E}\,\hat{\pi}_1, \\ 1 & \text{if} \quad \mathrm{E}\,\hat{\pi}_0 - \beta F < \mathrm{E}\,\hat{\pi}_1. \end{cases} \tag{6}$$

There are three possible symmetric equilibria: two pure strategy equilibria ($\alpha = 0$ and $\alpha = 1$), and a strictly mixed strategy equilibrium in which $\alpha \in (0, 1)$. We will characterize each of these equilibria in turn and then present the intuition underlying our main results. Consider the pure strategy equilibria first. In an equilibrium with universal non-compliance ($\alpha = 0$), $(\mathrm{E}\,\hat{\pi}_0 - \beta F \mid_{\hat{\alpha}=0}) > \mathrm{E}\,\hat{\pi}_1 \mid_{\hat{\alpha}=0}$. Using (5a) and (5b), this implies

$$\beta F < \left\{[2(a-c_0)]^2 - [2(a-c_1) - (n-1)(c_1-c_0)]^2\right\}/4b(n+1)^2. \tag{7}$$

Define $\underline{\beta F}$ as the βF that satisfies (7) with equality. Any expected fine less than $\underline{\beta F}$ will induce universal non-compliance. Differentiating $\underline{\beta F}$ with respect to n leads to our first result.

Proposition 1a. The minimum expected fine required to induce some degree of compliance ($\alpha > 0$) is decreasing in n. That is $\partial(\underline{\beta F})/\partial n < 0$.

Proof. Given the value of βF in (7), and using (4a) and (4b):

$$\underline{\beta F} = \frac{(c_1 - c_0)}{2}(\hat{q}_0 + \hat{q}_1) \mid_{\hat{\alpha}=0}. \tag{8}$$

Differentiating with respect to n then yields

$$\frac{\partial \underline{\beta F}}{\partial n} = -\frac{(a-c_0)(c_1-c_0)}{b(n+1)^2}. \tag{9}$$

Since $a > c_1 > c_0$, it follows that $\partial(\underline{\beta F})/\partial n < 0$. Q.E.D.

Then consider the equilibrium with universal compliance ($\alpha = 1$). In that case, $(\mathrm{E}\,\hat{\pi}_0 - \beta F\,|_{\hat{\alpha}=1}) < \mathrm{E}\,\hat{\pi}_1\,|_{\hat{\alpha}=1}$. Using (5a) and (5b), this implies

$$\beta F > \left\{[2(a-c_0)+(n-1)(c_1-c_0)]^2 - [2(a-c_1)]^2\right\}/4b(n+1)^2. \tag{10}$$

Define $\overline{\beta F}$ as the βF that satisfies (10) with equality. Any expected fine greater than $\overline{\beta F}$ will induce compliance.

Proposition 1b. The minimum expected fine required to induce universal compliance ($\alpha = 1$) *is decreasing in* n. *That is* $\partial(\overline{\beta F})/\partial n < 0$.

Proof. Given the value of $\overline{\beta F}$ in (10), and using (4a) and (4b):

$$\overline{\beta F} = \frac{(c_1-c_0)}{2}(\hat{q}_0 + \hat{q}_1)\,|_{\hat{\alpha}=1}. \tag{11}$$

Differentiating with respect to n then yields

$$\frac{\partial(\overline{\beta F})}{\partial n} = -\frac{(a-c_1)(c_1-c_0)}{b(n+1)^2}.$$

Since $a > c_1 > c_0$, it follows that $\partial(\overline{\beta F})/\partial n < 0$. Q.E.D.

We now turn to the strictly mixed strategy equilibrium, in which $\alpha \in (0, 1)$. In this equilibrium, $\mathrm{E}\hat{\pi}_0 - \beta F = \mathrm{E}\,\hat{\pi}_1$.

Proposition 2. For $\beta F \in (\underline{\beta F}, \overline{\beta F})$, *a unique symmetric mixed strategy equilibrium exists.*

Proof. First, note that for $\beta F = 0$, $\mathrm{E}\,\pi_0\,|_{\hat{\alpha}=0} > \mathrm{E}\,\pi_1\,|_{\hat{\alpha}=0}$. Second, from (5a) and (5b) note that $\partial\,\mathrm{E}\,\pi_0/\partial\hat{\alpha} > \partial\,\mathrm{E}\,\pi_1/\partial\hat{\alpha}$. Hence, for $\beta F \in (\underline{\beta F}, \overline{\beta F})$ there is a unique symmetric equilibrium in which $\hat{\alpha} \in (0, 1)$. Q.E.D.

Proposition 3. Ceteris paribus, the equilibrium probability of compliance ($\hat{\alpha}$) *increases with the number of firms in the industry.*

Proof. At the strictly mixed strategy equilibrium, $\mathrm{E}\,\hat{\pi}_0 - \beta F = \mathrm{E}\,\hat{\pi}_1$. Using (4a) and (4b), this can be written as

$$(\hat{q}_0 + \hat{q}_1) = 2\beta F/(c_1 - c_0). \tag{12}$$

Totally differentiating (12) with respect to n and $\hat{\alpha}$, we obtain

$$\frac{\mathrm{d}\hat{\alpha}}{\mathrm{d}n}=\frac{2[a-c_0-\hat{\alpha}(c_1-c_0)]}{(n+1)(n-1)(c_1-c_0)}. \tag{13}$$

Given that $a > c_1 > c_0$, it follows that $\mathrm{d}\hat{\alpha}/\mathrm{d}n > 0$. Q.E.D.

The intuition underlying Propositions 1 and 3 is as follows. In a Cournot equilibrium, profits are a declining function of marginal production cost but the rate of change depends on the number of firms in the industry. The impact of higher costs on expected profitability is most severe in industries with few firms (because the higher cost is incurred on a larger individual output). That is, $\partial^2 \mathrm{E}\,\pi/\partial c\,\partial n < 0$. This means that the effective cost of compliance is higher in industries with fewer firms. Conversely, the effect of an expected fine on profitability is independent of the number of firms because the expected fine is a fixed cost. Hence, the expected fine required to induce compliance is decreasing in n (Proposition 1) and the expected level of compliance for a given expected fine is increasing in n (Proposition 3).

3. Policy implications

The foregoing analysis suggests that for a given expected penalty, non-compliance with environmental standards is likely to be most common in industries with a small number of firms. From the perspective of policy design, our results suggest that a given target level of compliance can be achieved in an industry comprising many firms with a lower expected penalty than in industries with fewer firms. This may be a comforting result from the regulator's perspective, in view of the higher resource costs required to achieve a given level of monitoring in an industry with many firms. It suggests that it might be possible to spread scarce monitoring resources across a large number of firms without necessarily sacrificing compliance levels. However, this will depend on the nature of constraints on feasible fines. Recall from the introduction that arbitrarily large fines are generally not feasible. This naturally leads one to ask whether the feasible magnitude of the fine is related to industry size. If the non-complying firm's profitability is a relevant constraint, then clearly the answer is yes. Polinksy and Shavell (1991) have shown in a general law enforcement setting that optimal fines are constrained by the wealth of potential offenders. The reason is straightforward: potential offenders know that it is not possible to collect from them a fine that exceeds their ability to pay. Hence, a fine that is set too high relative to an individual's wealth will have a lesser deterrence effect than a lower fine levied with a higher probability. A similar constraint is likely to apply to the design of noncompliance penalties. The choice of penalty will generally have to be tailored to the profitability of the firms concerned. Note moreover that the penalty imposed upon conviction was assumed independent of the importance of the violation. It should also be noted that the paper does not address the issue of identifying the set of firms of a *given* industry most likely to be in non-compliance. These issues are the subject of ongoing research.

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